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By the end of the month shortages of soil moisture had developed over parts of New Mexico, Arkansas, Louisiana, and Alabama; and also in Illinois and Indiana. Dry weather continued in Washington, where Walla Walla reported its driest January-to-June period, and in north-central California, where the accumulation at Red Bluff in the last six months was the least of record. In addition, Pendleton, Oreg. reported its driest May.

Deficiency of precipitation east of the Rocky Mountains can be attributed to the anticyclonic character of the mean circulation (fig. 5). In the West the circulation was cyclonic and 1–2 in. of rain fell from California to Montana east of the mean trough. Scattered wet areas from Oklahoma to Wisconsin are less well related to the monthly circulation, but the weak anomalous flow from the south suggests the availability of moisture aloft. Irregular distribution of precipitation east of the Rocky Mountains indicates the lack of a well-defined storm path.

Comparison of the distributions for May and Spring

(fig. 9B) shows the areas where deficiency in May was part of a longer-period dry state. In the critically dry region from New England to North Carolina totals for Spring were less than 75 percent of normal. In the Midwest and parts of the South the need for moisture was not so great, despite the shortage in May, because of adequate supplies in previous months.

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Weather Note

LARGE HAIL IN CENTRAL MONTANA, JUNE 28, 1963

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1. INTRODUCTION

A fall of large hailstones at Flatwillow 4 ENE, a Montana climatological substation, about 0700 MST, June 28, 1963, provided an unusual opportunity for study of the stones when observer S. E. Wiggins, on his own initiative, carefully preserved several stones in his home freezer. When the station, located in central Montana's Petroleum County (fig. 1) was visited about two months later, Montana Field Aide, E. L. Stensland, examined and sketched several of the larger stones. The stones were dissected for study, and the purposes of this note are to record descriptions; to describe some of the atmospheric conditions probably involved in their formation, and to comment on some possible implications arising from stone size and structure.

2. DESCRIPTION OF STONES

Four stones were chosen for dissection, study, and measurement. Sketches of the four appear in figures 2–5; scales are shown for each. The stone sketched in figure 2 had an original average circumference of 9.8 in. (average diameter 3.2), with rings quite distinct about as shown. The stone sketched in figure 3 had an original circum-

ference of 10.5 in. the long way, 4.7 in. the small way (diameters 3.4 and 1.5 in. respectively). The stone pictured in figure 4 had an average diameter 2.5 in., circumference about 7.9 in. The stone in figure 5 appeared to have melted flat on one side, but could originally have been the largest of the four, with an estimated 3.5-in.

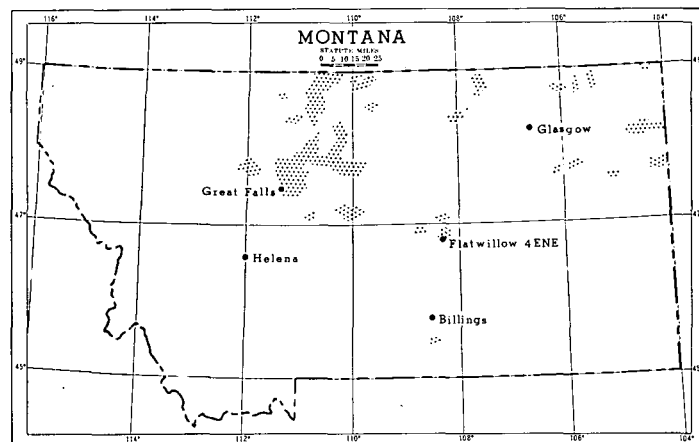


FIGURE 1.—Map of Montana showing location of Flatwillow 4 ENE, the station where the large hailstones fell, June 28, 1963. Shaded areas reported hail damage to crops that day.

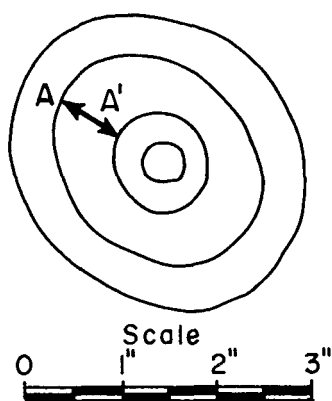


FIGURE 2.—Sketch of one of the more symmetrical hailstones. Original circumference 9.8 in. Note the four rings and the 0.7-in. thickness at A-A'.

diameter. There is also the possibility that this stone was soft enough—at least in some of its layers—to have been flattened to some extent by first impact with the ground.

The number of rings shown in each case of figures 2–5 is accurate. They were quite distinct when the stones were sawed or cracked open. In exterior appearance they were very much like the large stones pictured by Ludlam [1]. The large thickness of some of the rings is noteworthy, as at A-A', figure 2, where the ring dimension is 0.7 in. That the stones had been stored in a freezer of course allows no definite conclusion about hardness or softness of the layers, but the fact that most of the stones seemed to have survived ground impact without serious damage or distortion leads to a tentative conclusion that ice of reasonable hardness predominated, at least in all stones except that of figure 5, and even there melting could have caused most if not all of the loss. A good explanation of how the stone in figure 3 developed its shape seems difficult.

3. COMMENTS ON FORMATION OF RINGS

While there is uncertainty about just how successive rings of ice are added in the processes of formation and building of hailstones, as summarized by Ludlam [1] and List [2], it appears that the rate of ice accumulation was fairly rapid for all four stones. Note in figure 2 the next to outer ring of the stone, with an average thickness of about 0.6 inch. Other deductions become a bit tenuous, but it may be noted that the stone in figure 2 could have required as many as four growth surges into the icing zone of the thunderhead, or as few as two, according to Ludlam [1] and Douglas [3], since the falling part of an accretion cycle may or may not result in a distinguishable ring. Similar speculation may be applied to the other stones pictured, and gives us a range of from 2 to 4 growth surges—although 6 are possible for the stones in figures 3 and 4.

Positive (upward) vertical air motion required to sup-

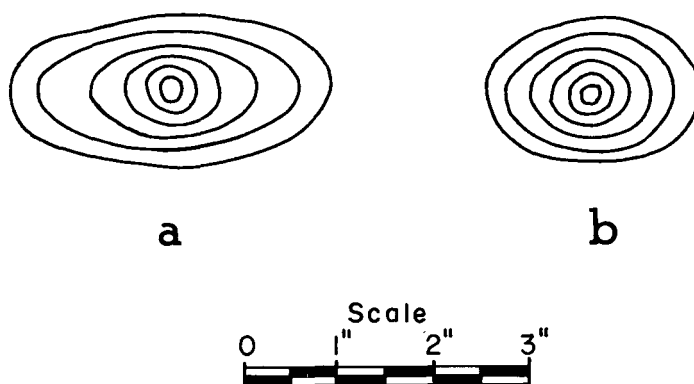


FIGURE 3.—(a) Side view and (b) end view of stone whose original measurements were (long way) 10.5 in. and (small way) 4.7 in. Greatest cross dimension was 3.4 in.; smallest, 2.2 in. Six rings were easily identifiable.

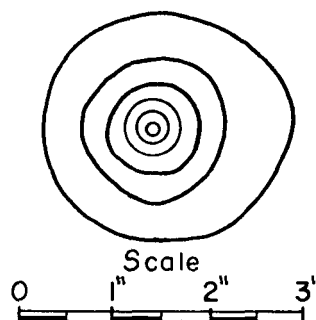


FIGURE 4.—Cross section of hailstone 1.5 in. in diameter. This was one of the more nearly spherical stones. Again six rings were identifiable.

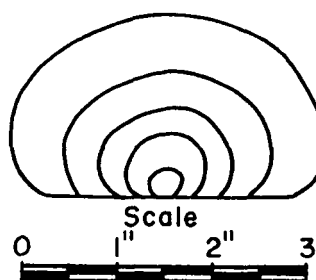


FIGURE 5.—Original stone could have been nearly round; it seems likely that some melting took place before it was stored in freezer, or it could have been flattened on impact. Largest radius remaining measured 2 in.; original stone might have been about 3.5 in. in diameter.

port such stones against the acceleration of gravity is of real interest. While measurements obviously were not possible, some of the theoretical work done in this field by Ludlam [1], Humphreys [4], U.S. Weather Bureau [5], and Bilham and Relf [6] permits some reasonable estimates. If it is assumed that the maximum vertical speed must closely approach the terminal fallout speed, for the stone in figure 2 (density estimated 0.9) that speed would approximate 130 to 140 m.p.h. according to Humphreys

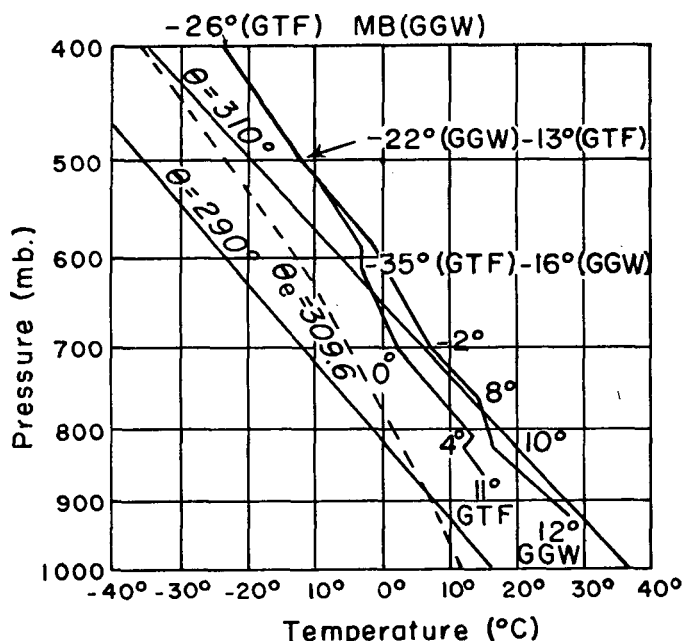


FIGURE 6.—Raob soundings for Great Falls (GTF) and Glasgow (GGW) Mont., 1700 MST, June 28, 1963. Actual lapse rates are shown with dew point values plotted. Sounding lapse rates coincide between 500 and 400 mb. but note dew point differences.

[4], about 100 m.p.h. according to [5], and about 72 m.p.h. for a 5–10 cm. diameter according to Ludlam [1]. Bilham and Relf [6], on the basis of assuming a maximum updraft component of about 150 m.p.h., calculated a maximum supportable hail diameter (spherical stone) of about 4.3 in. (11 cm.). This calculation was based upon the rapid decrease in the drag coefficient which begins when the Reynolds number exceeds about 2×10^5 , and it seems unlikely that spherical stones much larger than that size (4.3 in.) can occur.

In the cases of these stones, assuming a rough surface, a reasonable vertical speed estimate would be 70 to 90 m.p.h. This assumes that Humphreys' [4] stones were smooth, in addition to the other assumptions listed in his report. The obvious strength of such vertical motions is one of the primary reasons (well-known to pilots) that aircraft should avoid thunderstorms. Equally important reasons are the possible extreme rates of clear ice accumulation above the freezing level, and the obvious consequences of direct collision of aircraft with stones of these sizes.

4. METEOROLOGICAL CONDITIONS

A complete analysis of the synoptic features involved is beyond the scope of this note. Some hail damage esti-

mates for June 28 are given in [7] and areas of crop damage are hatched in figure 1. In a broad sense Dickson [8] covers some of the large-scale meteorological features. The features on the daily weather map were not unusual; perhaps most significant were the early morning surface dew points in the 50°–60° F. range over much of eastern Montana. At 500 mb., however, a ridge line was moving slowly eastward over the Dakotas and Minnesota, and the winds over Montana by mid-afternoon had backed to the southwest and were advecting colder and dryer air at upper levels (around 700 to 500 mb.), while the moist layers near the surface were still in evidence (late afternoon dew points in the area still were near 60° F.). The resulting decrease in stability was compounded by solar radiational heating of lower layers during the afternoon.

In figure 6 are plots of Glasgow and Great Falls raob soundings at 1700 MST June 28—near the time of the fall of the large stones (see locations, fig. 1). Glasgow was almost directly downstream from Flatwillow, and had 1.01 in. of precipitation, but no hail, in less than 4 hours beginning after 2000 MST that evening. The features of instability (Glasgow stability index about -6), water vapor, etc., are apparent and require no comment. The temperature differences between Glasgow and Great Falls below the 600-mb. level were also significant; the cooling at Great Falls, during the preceding 12 hr., at 700 mb. amounted to nearly 5° C., while Glasgow showed little change other than the development of a superadiabatic lapse rate below the 815-mb. level by 1700 MST.

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